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(54) **SYSTEM AND METHOD FOR ANALYZING MALICIOUS CODE USING A STATIC ANALYZER**

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H04L 29/06	(2006.01)
G06F 21/55	(2013.01)

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USPC 726/4, 22, 24, 2

See application file for complete search history.

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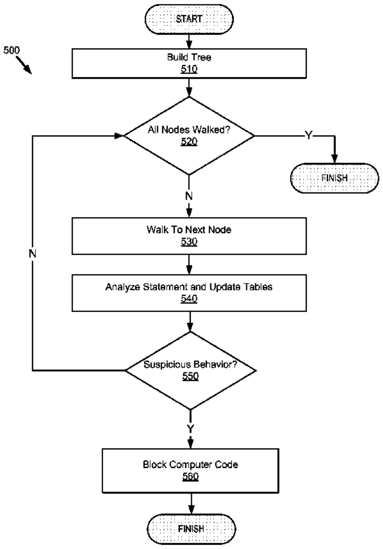
(57) **ABSTRACT**

Analyzing computer code using a tree is described. For example, a client device generates a data request for retrieving data from a non-trusted entity via a network. A gateway is communicatively coupled to the client device and to the network. The gateway is configured to receive computer code from the non-trusted entity via the network. The gateway builds a tree representing the computer code. The tree has one or more nodes. A node of the tree represents a statement from the computer code. The gateway analyzes the statement to identify symbol data. The symbol data describes a name of the variable and the value of the variable. The gateway stores the symbol data in a symbol table.

20 Claims, 9 Drawing Sheets



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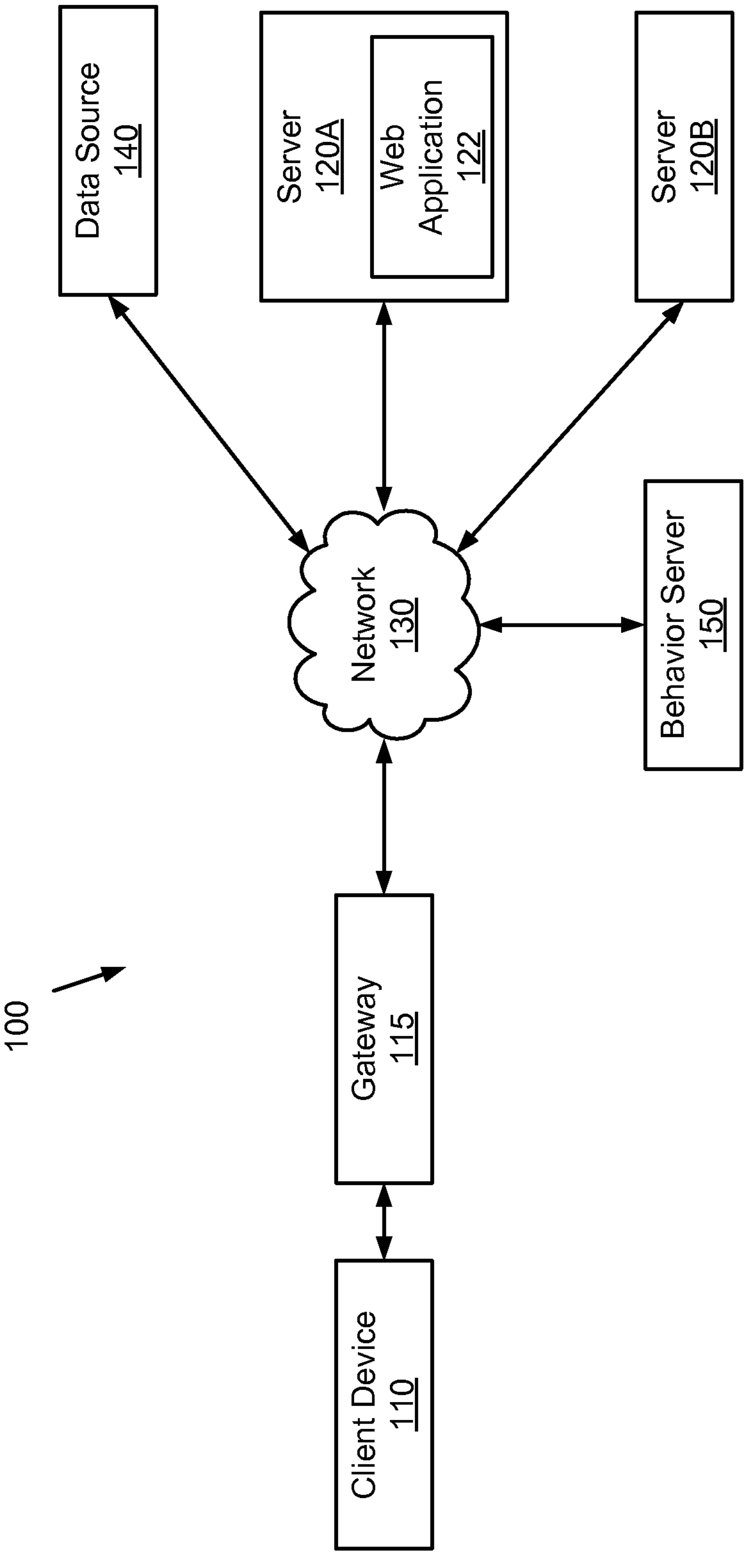
100
Data Source 140
Server 120A
Web Application 122
Server 120B
Network 130
Behavior Server 150
Gateway 115
Client Device 110

Figure 1

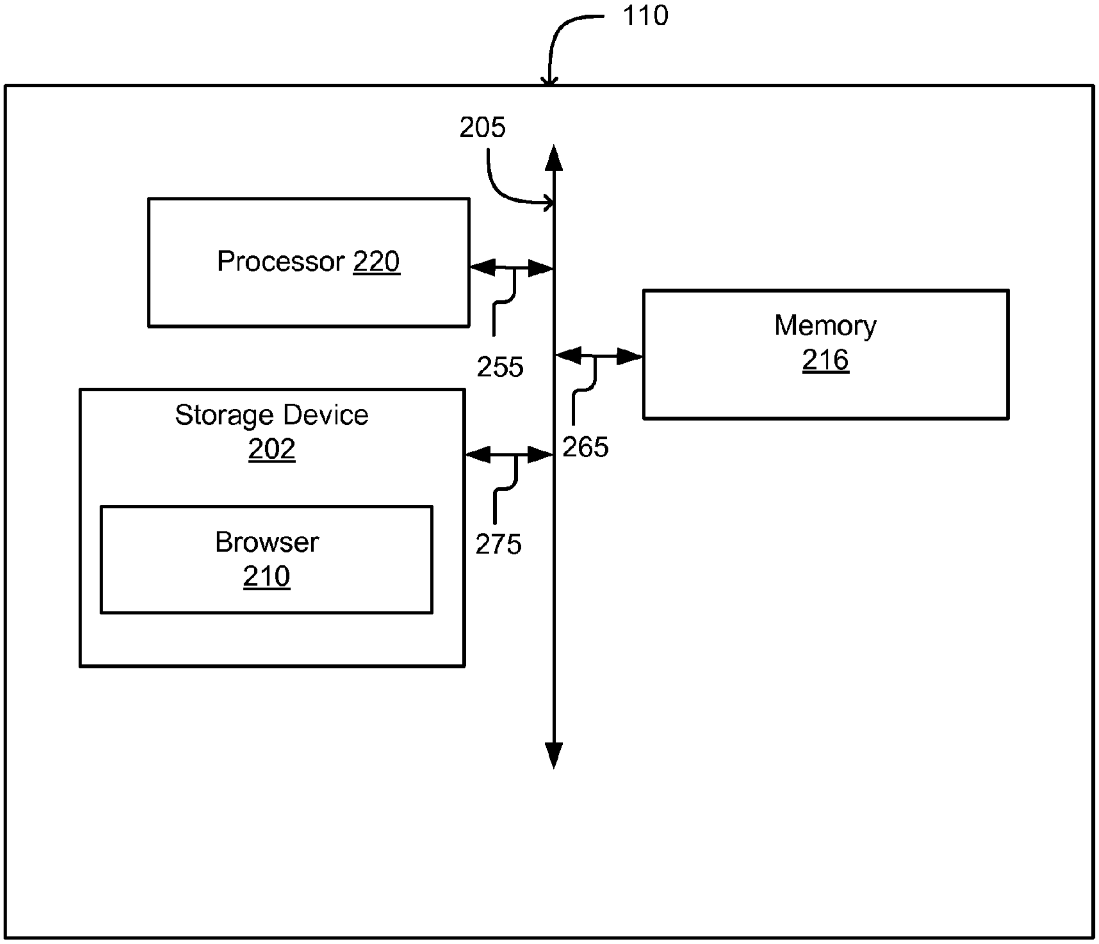
110
205
Processor 220
Memory 216
255
265
Storage Device 202
Browser 210
275

Figure 2

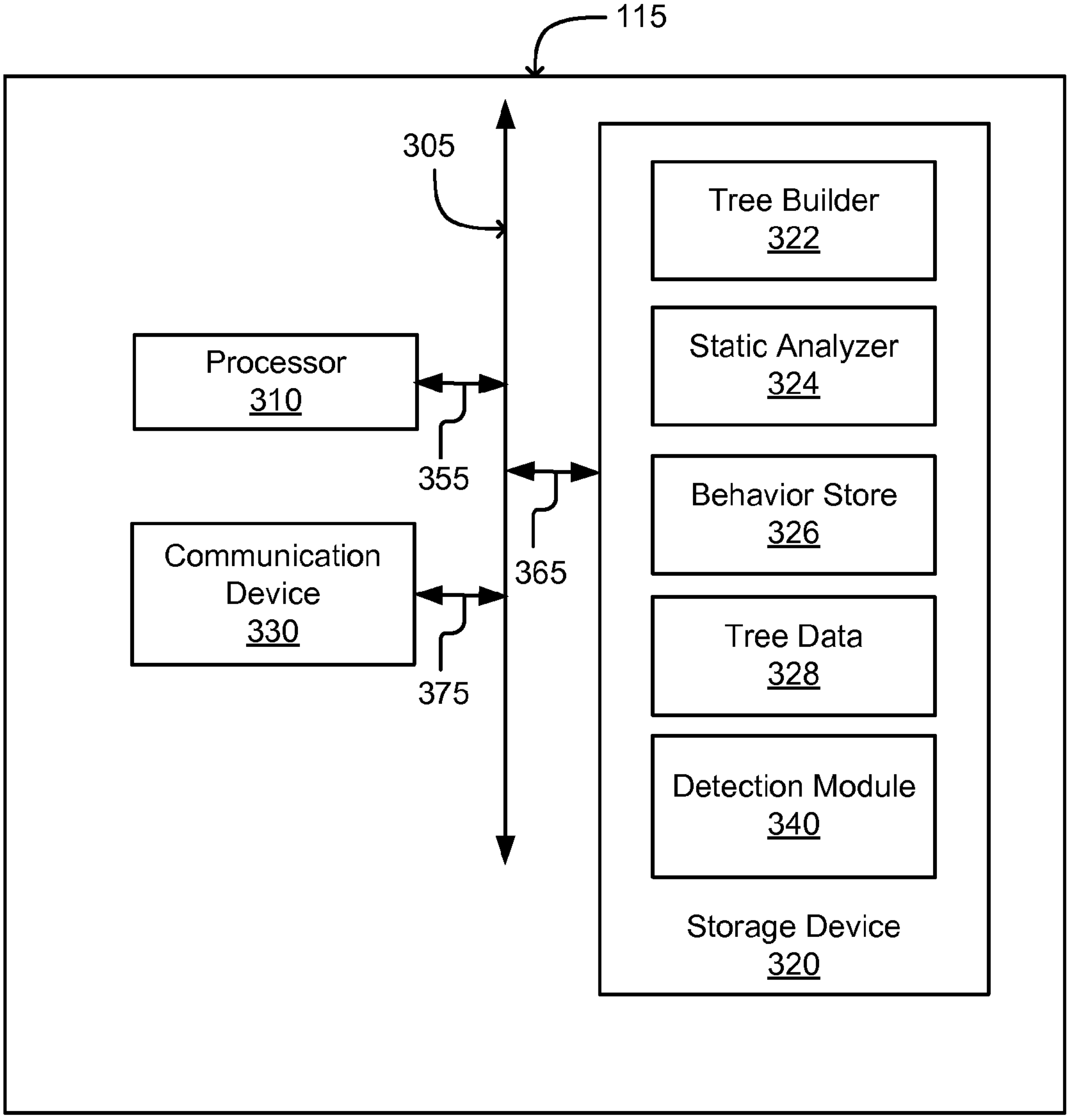
115
305
Processor
310
355
Communication
Device
330
375
365
Tree Builder
322
Static Analyzer
324
Behavior Store
326
Tree Data
328
Detection Module
340
Storage Device
320

Figure 3

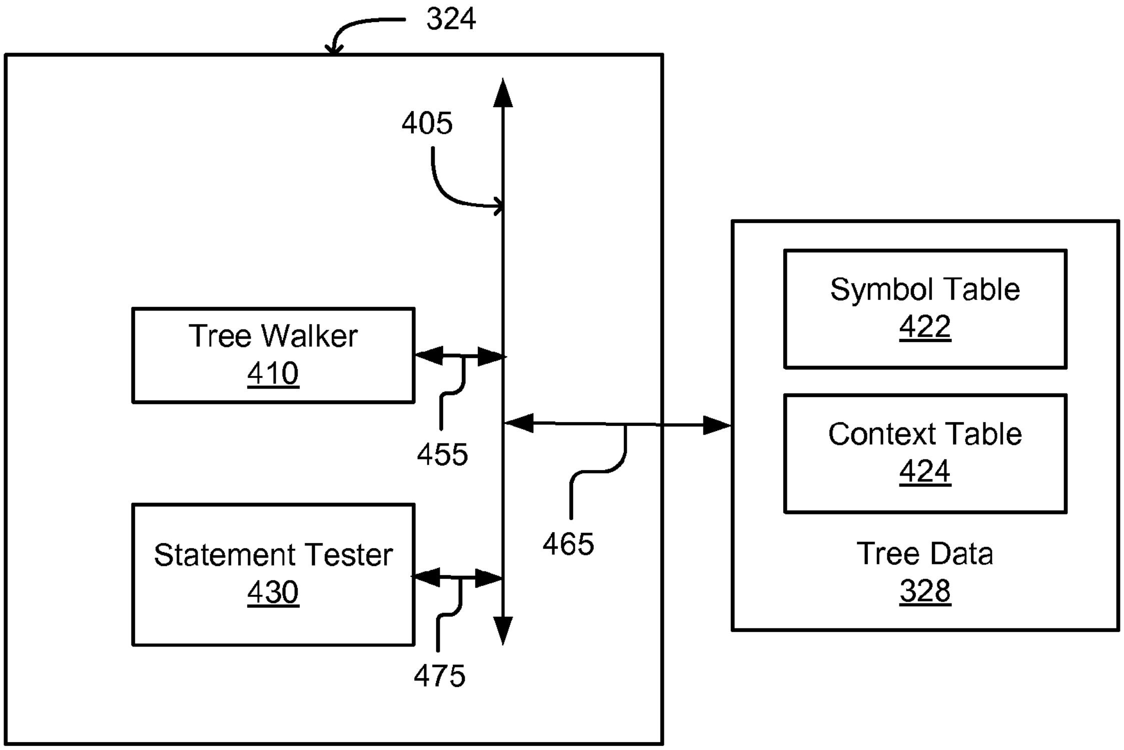
324
405
Tree Walker
410
455
Statement Tester
430
475
465
Symbol Table
422
Context Table
424
Tree Data
328

Figure 4

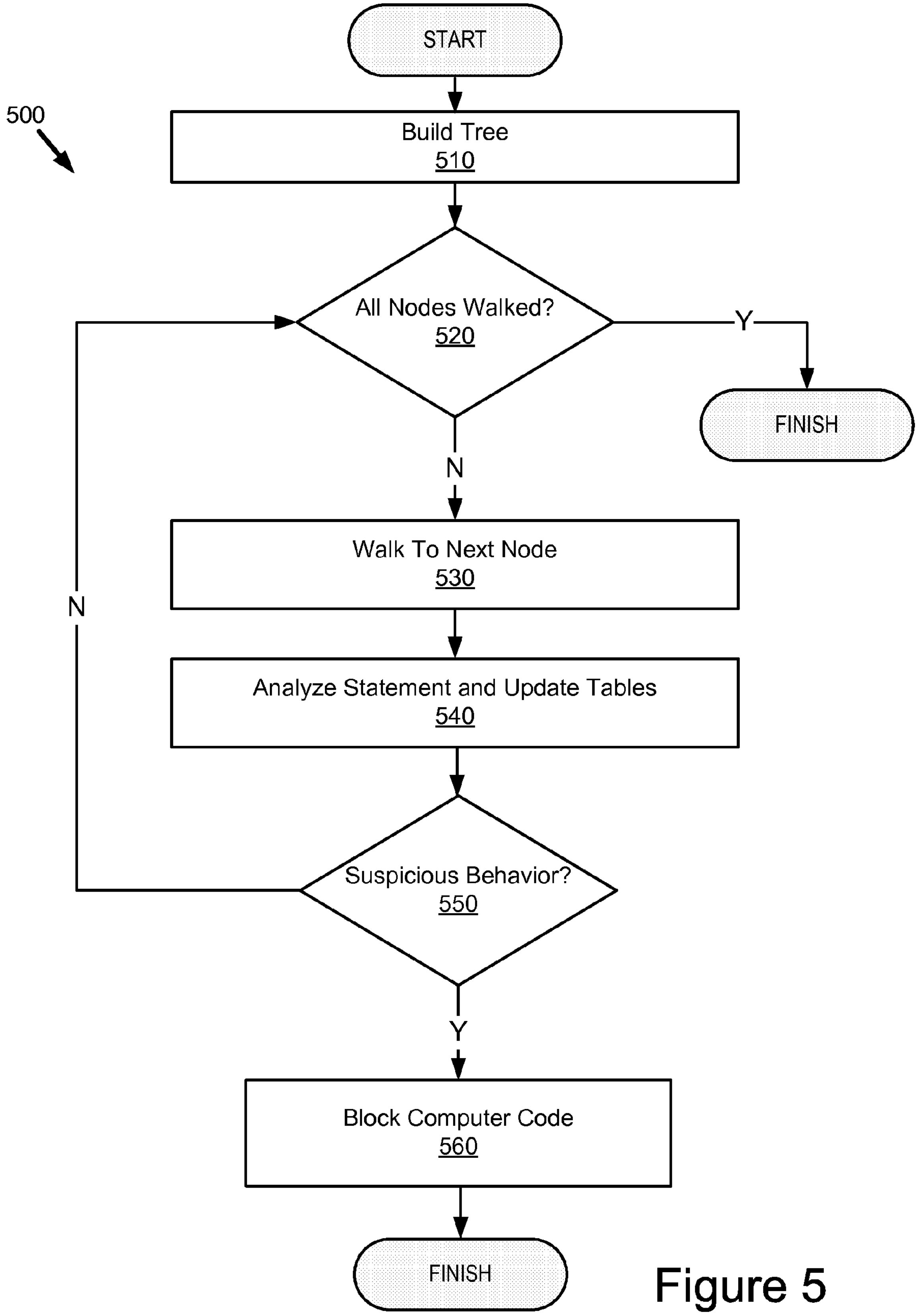
START
500
Build Tree
510
All Nodes Walked?
520
Y
FINISH
N
Walk To Next Node
530
N
Analyze Statement and Update Tables
540
Suspicious Behavior?
550
Y
Block Computer Code
560
FINISH

Figure 5

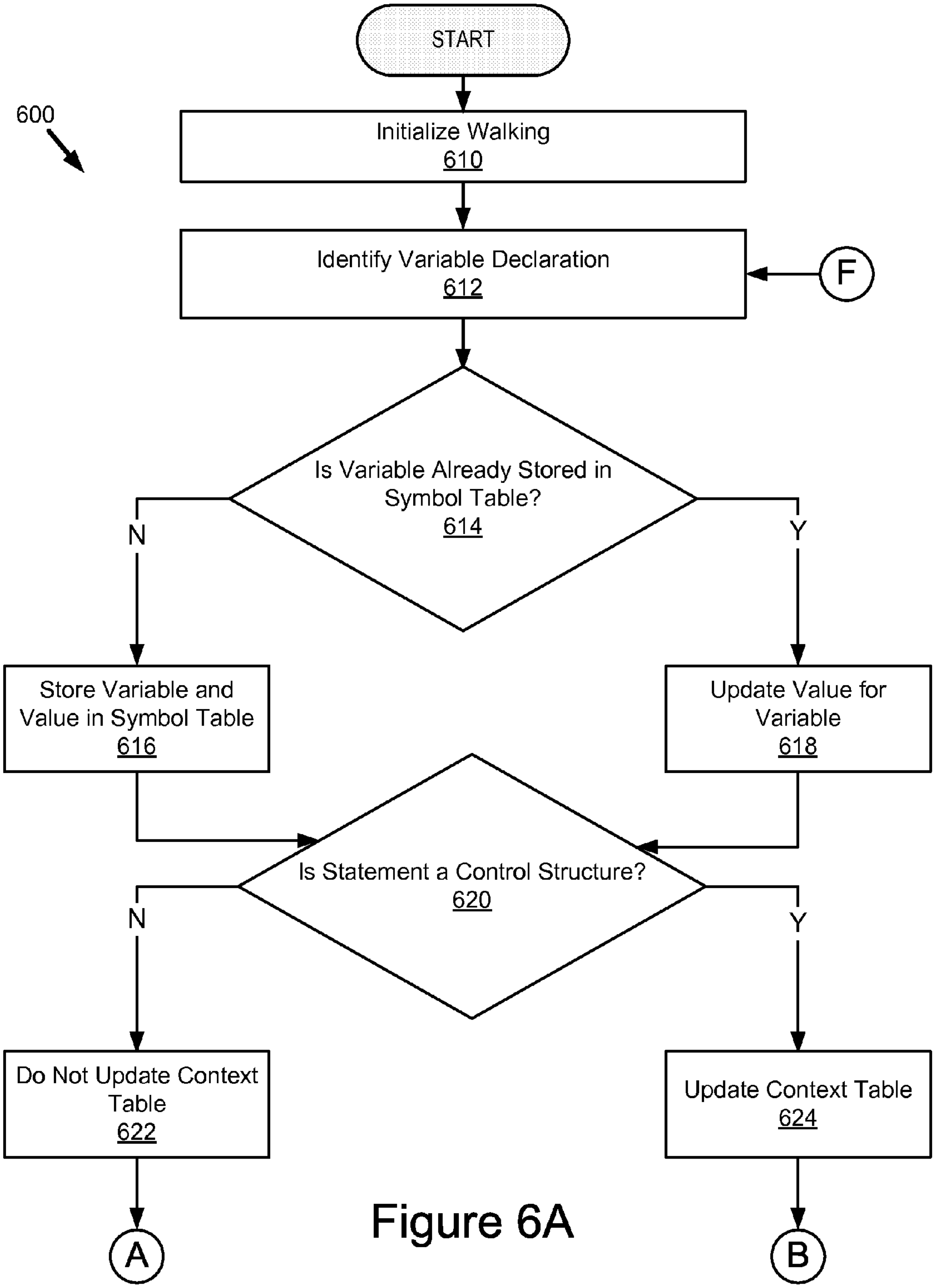
START
600
Initialize Walking
610
Identify Variable Declaration
612
F
Is Variable Already Stored in Symbol Table?
614
N
Y
Store Variable and Value in Symbol Table
616
Update Value for Variable
618
Is Statement a Control Structure?
620
N
Y
Do Not Update Context Table
622
Update Context Table
624
A
B

Figure 6A

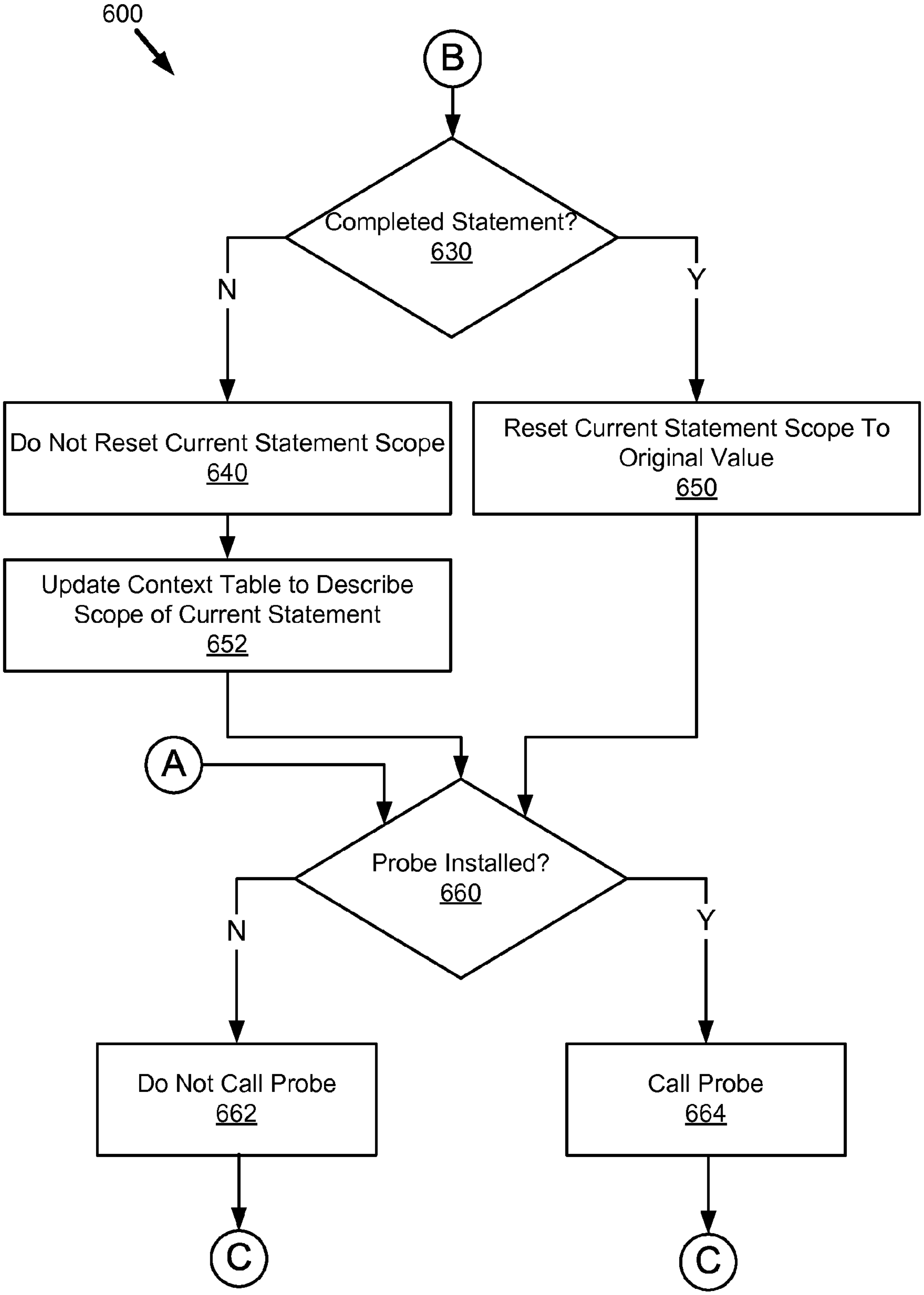
600
B
Completed Statement?
630
N
Y
Do Not Reset Current Statement Scope
640
Reset Current Statement Scope To Original Value
650
Update Context Table to Describe Scope of Current Statement
652
A
Probe Installed?
660
N
Y
Do Not Call Probe
662
Call Probe
664
C
C

Figure 6B

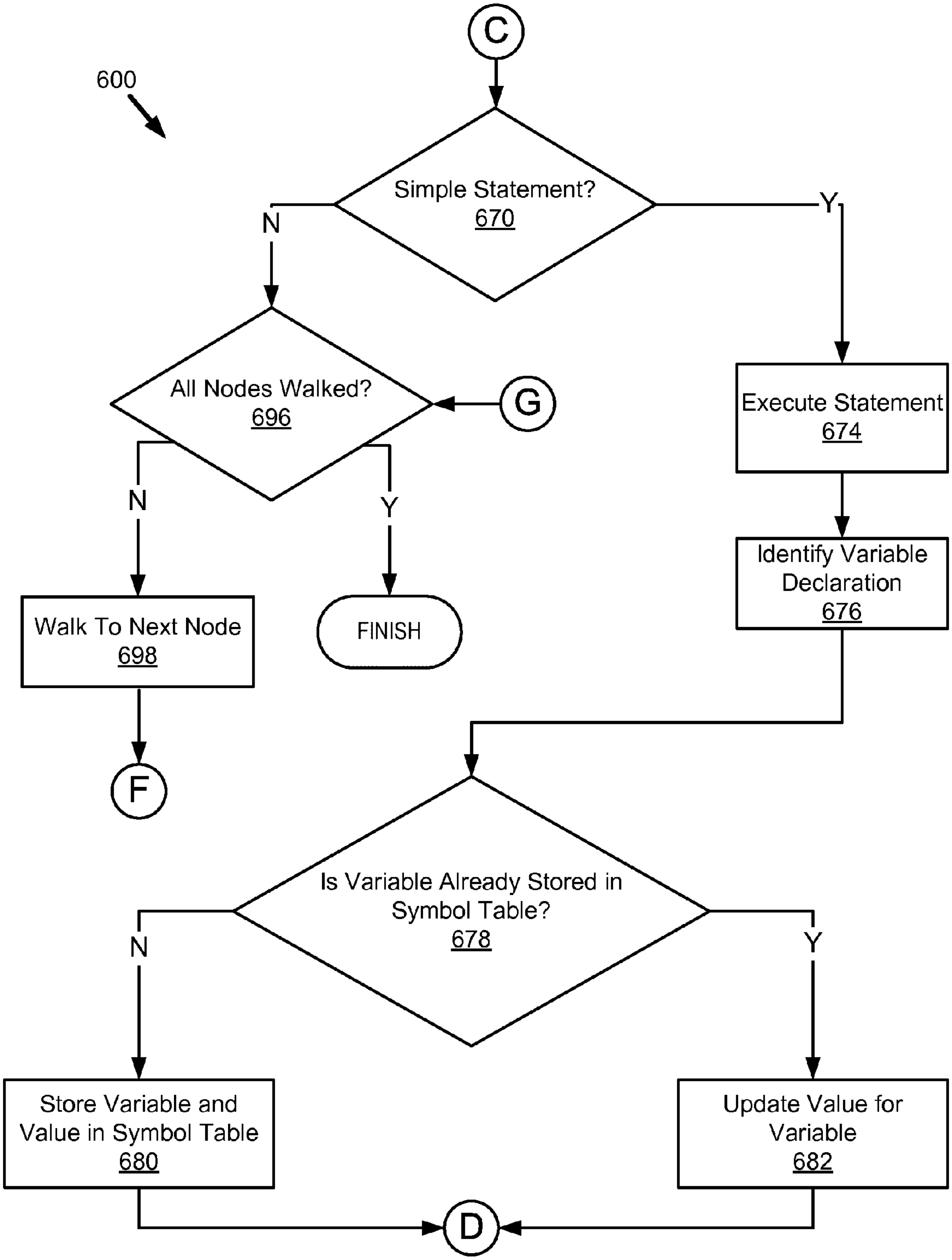
600
C
Simple Statement?
670
N
Y
All Nodes Walked?
696
G
Execute Statement
674
N
Y
Walk To Next Node
698
FINISH
Identify Variable Declaration
676
F
Is Variable Already Stored in Symbol Table?
678
N
Y
Store Variable and Value in Symbol Table
680
Update Value for Variable
682
D

Figure 6C

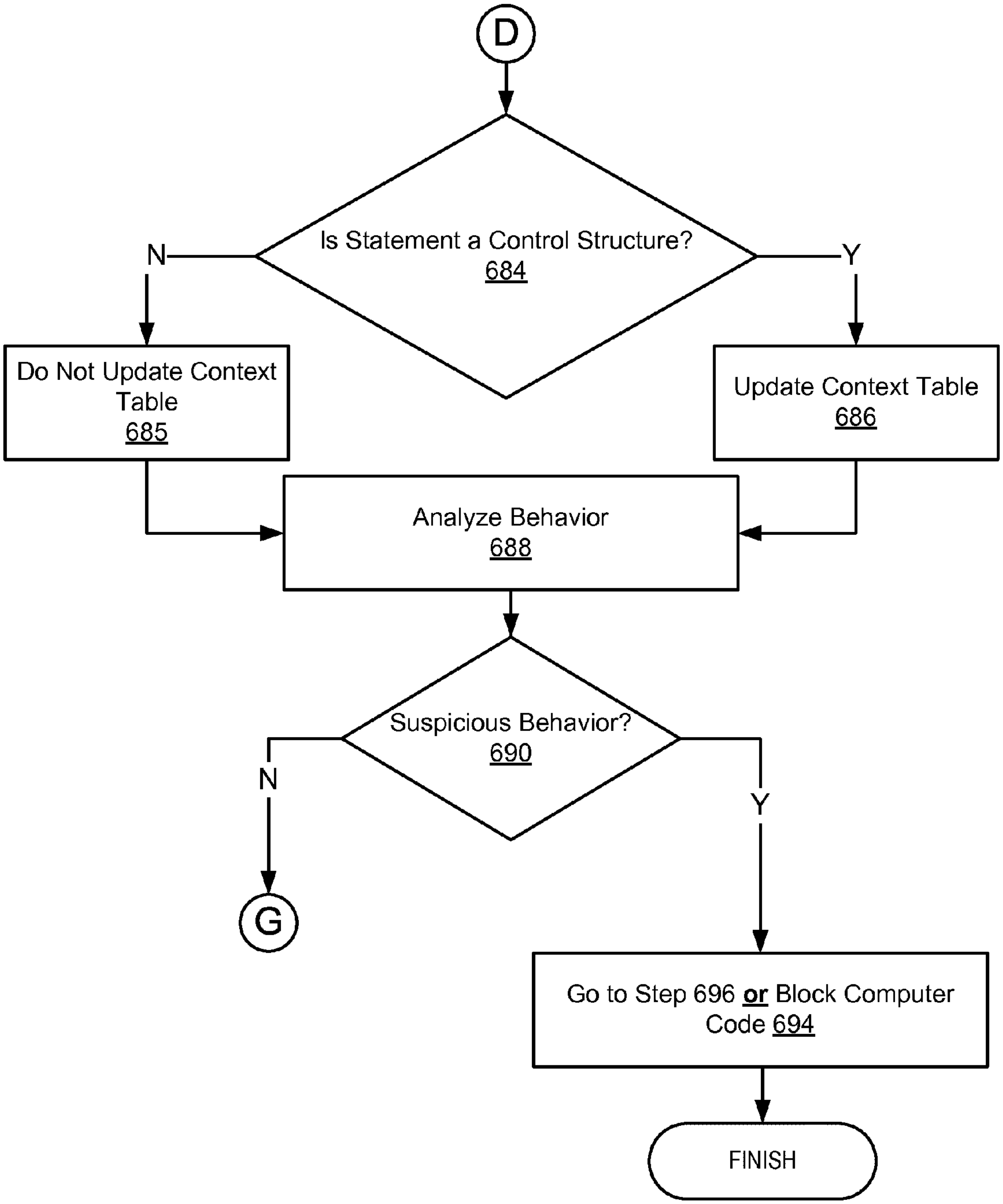
D
Is Statement a Control Structure?
684
N
Y
Do Not Update Context Table
685
Update Context Table
686
Analyze Behavior
688
Suspicious Behavior?
690
N
Y
G
Go to Step 696 or Block Computer Code 694
FINISH

Figure 6D

SYSTEM AND METHOD FOR ANALYZING MALICIOUS CODE USING A STATIC ANALYZER

CROSS REFERENCE

This application claims priority from the following U.S. provisional patent application, which is hereby incorporated by reference: Ser. No. 61/353,957, filed on Jun. 11, 2010, and entitled "Method and System for Detecting Malicious Content."

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to malware detection and in particular to a static analyzer for analyzing malicious computer code.

2. Description of the Background Art

Computer networks and systems have become indispensable tools for modern data communication. Terabits of information are communicated by computer networks throughout the world. Much of this information is, to some degree, confidential and its protection is required. However, security threats have become increasingly able to evade conventional signature or pattern based detection techniques. This problem is enhanced with advent of widespread use of dynamic computer code such as JavaScript in websites. In addition to viruses, additional types of malicious software ("malware"), such as cross-site scripting and Trojans, have become increasingly common methods for impeding the performance of the client device and accessing sensitive information stored on client device.

More information about the malware is necessary to improve network security. It is therefore useful to acquire information describing computer code that is received from non-trusted entities.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide a system and method analyzing computer code using a tree. A client device generates a data request for retrieving data from a non-trusted entity via a network. A gateway is communicatively coupled to the client device and to the network. The gateway is configured to receive computer code from the non-trusted entity via the network. The gateway builds a tree representing the computer code. The tree has one or more nodes. A node of the tree represents a statement from the computer code. The gateway analyzes the statement to identify symbol data. The symbol data describes a name of the variable and a value of the variable. The gateway stores the symbol data in a symbol table. In one embodiment, the gateway analyzes the statement to determine context data describing the scope of the variable. The gateway stores the context data in a context table.

The features and advantages described herein are not all-inclusive and many additional features and advantages will be apparent to one of ordinary skill in the art in view of the figures and description. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example, and not by way of limitation in the figures of the accompanying drawings in which like reference numerals are used to refer to similar elements.

FIG. **1** is a block diagram of a system for using a static analyzer to analyze computer code according to one embodiment.

FIG. **2** is a block diagram of a client device according to one embodiment.

FIG. **3** is a block diagram of a gateway according to one embodiment.

FIG. **4** is a block diagram of a static analyzer according to one embodiment.

FIG. **5** is a flow chart of a method for using a static analyzer to analyze computer code according to one embodiment.

FIGS. **6**A, **6**B, **6**C and **6**D are a flow chart of a method for using a static analyzer to analyze computer code according to another embodiment.

DESCRIPTION OF EMBODIMENTS

A method and system for using a static analyzer to analyze computer code in accordance with the present invention is described below. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the invention. It will be apparent, however, to one skilled in the art that the invention can be practiced without these specific details. In other instances, structures and devices are shown in block diagram form in order to avoid obscuring the invention.

Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

Some portions of the detailed descriptions that follow are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The present invention also relates to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may comprise a general-purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic instructions, each coupled to a computer system bus.

The invention can take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment containing both hardware and software elements. In one embodiment, the invention is implemented in software, which includes but is not limited to firmware, resident software, microcode, etc.

Furthermore, the invention can take the form of a computer program product accessible from a computer-usable or computer-readable medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer-usable or computer readable medium can be any apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer-readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W) and DVD.

A data processing system suitable for storing and/or executing program code will include at least one processor coupled directly or indirectly to memory elements through a system bus. The memory elements can include local memory employed during actual execution of the program code, bulk storage, and cache memories which provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

Input/output or I/O devices (including but not limited to keyboards, displays, pointing devices, etc.) can be coupled to the system either directly or through intervening I/O controllers.

Network adapters may also be coupled to the system to enable the data processing system to become coupled to other data processing systems or remote printers or storage devices through intervening private or public networks. Modems, cable modem and Ethernet cards are just a few of the currently available types of network adapters.

Finally, the algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general-purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description below. In addition, the present invention is described with reference to a particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

System Overview

FIG. **1** is a diagram of a system **100** for using a static analyzer to analyze computer code according to one embodiment. In the embodiment of FIG. **1**, the system **100** includes a client device **110**, a first server **120**A, a second server **120**B and a data source **140** exchanging data with each other via a network **130**. Additionally, in the embodiment shown by FIG. **1**, the client device **110** is coupled to a gateway **115**, which is coupled to the network **130**. Thy system **100** also includes a behavior server **150**. In other embodiments, the system **100** includes additional and/or different components than the ones shown in FIG. **1**.

The client device **110** is a computing device having data processing and communication capabilities. For example, a client device **110** comprises a desktop computer, a laptop computer, a netbook computer, a tablet computer, a smartphone or an internet capable television. While the system **100** shown by FIG. **1** includes a single client device **110**, in other embodiments, the system **100** includes multiple client devices **110**. For example, different types of client devices **110** are included in the system **100**, such as a smartphone, a tablet computer and/or a laptop computer.

The client device **110** executes instructions or data using a processor to store, retrieve, modify or otherwise access data. When executing one or more processes, the client device **110** may access data from a remote source, such as a server **120** or another data source **140** via the network **130**. To access remote data, the client device **110** transmits a data request to the server **120** or data source **140** via the network **130**. The data request identifies the requested data as well as the client device **110** and may include additional information for identifying and retrieving the data.

A gateway **115** is coupled to the client device **110** and to the network **130** and receives one or more data requests from the client device **110**. The gateway **115** communicates the data request to a first server **120**A, a second server **120**B or a data source **140** via the network **130**. The gateway **115** receives data from one or more of the first server **120**A, the second server **120**B and the data source **140** via the network **130**. For example, responsive to the data request, the gateway **115** receives data from one or more of the first server **120**A, the second server **120**B and the data source **140** via the network **130**. The gateway **115** is a computing device that couples one or more client devices **110** to a network **130**. For example, the gateway **115** is a router, a wireless access point, a network switch or any other suitable type of computing device. While FIG. **1** shows the gateway **115** as a separate component, in some embodiments the gateway **115** is included in the client device **110**.

In addition to communicating data requests and data between a client device **110** and the first server **120**A, the second server **120**B and the data source **140**, the gateway **115** also uses a static analyzer to analyze computer code. For example, the gateway **115** receives computer code from one or more of the data source **140**, the first server **120**A and the second server **120**B. In one embodiment, the computer code is any routine and/or script received from the web application **122** and/or the data source **140**. The gateway **115** analyzes the computer code, for example, to collect tree data describing the computer code.

Specifically, the gateway **115** parses the computer code to build a tree. For example, the gateway **115** parses the computer code to build an Abstract Syntax Tree ("AST" or "AST tree"). The AST tree is any form of AST tree. Each node of the tree includes one or more statements from the original computer code. In one embodiment, a node of the tree represents one or more statements occurring in the computer code. The gateway **115** stores a symbol table and a context table. The symbol table stores information describing one or more of the variables in the statement. For example, the gateway **115** parses a name and a value for a variable from the statement and stores the name and the value for the variable in the symbol table. The name and the value for the variable are referred to herein as "symbol data." The context table stores information describing the scope the variable described by the symbol data in the symbol table.

In one embodiment, the symbol data describes each variable by the variable name and the value for the variable. The gateway **115** determines whether the variable is a control statement. If the variable is a control statement, the gateway **115** analyzes the variable to determine the scope of the variable. The gateway **115** stores information describing the scope of the variable in a context table. The information describing the scope of the variable is referred to herein as "context data." In one embodiment, the symbol data for a variable is associated with a corresponding entry of context data stored in the context table. This association is stored in one or more of the symbol table and the context table. In another embodiment, the symbol table can have a variable name stored in it more than once, and the scope data stored in the context table (sometimes referred to as context data) can be used to differentiate the commonly named variables in the symbol table.

The gateway **115** analyzes the nodes of the tree to build and update the symbol table and the context table. This is described in further detail with reference to FIGS. **5** and **6**A-**6**D.

The gateway **115** determines whether the one or more statements are simple statements. In one embodiment, a simple statement is a statement consisting of basic algebraic operators or intrinsic language functions. Simple statements are described in more detail below with reference to FIGS. **4**, **5** and **6**A-**6**D. Responsive to determining that a statement is a simple statement, the gateway **115** executes the statement. The gateway **115** analyzes the execution of the simple statement and updates the symbol table and the context table with additional information describing the one or more variables of the simple statement and the scope of the one or more variables. For example, the gateway **115** analyzes changes in the values of a variable that occur responsive to executing the statement. These changes to the value are described by value data indicating the new value for the variable. The gateway **115** tracks these changes and updates the symbol table by the value data describing the new value in the symbol table. The gateway **115** also tracks the changes to the statement scope. The gateway **115** updates the context table by storing context data describing the changes to the statement scope in the context table.

In one embodiment, the gateway **115** monitors the executed statement for behavior indicating that the statement is a component of malicious computer code. As used herein, the term "malicious computer code" refers to computer code that is associated with malware or that otherwise seeks to impair performance of the client device **110** and/or gateway **115**, or transmit data from the client device **110** and/or gateway **115** without authorization.

The server **120**A comprises a web application **122**. The web application is code and routines that, when executed by a processor of the server **120**A (the processor is not pictured), causes the web application to transmit computer code to the client device **110**. In one embodiment, the computer code is any routine and/or script received from the web application **122** and/or the data source **140**. For example, the computer code is a script or routine written in JavaScript, Hypertext Transfer Protocol, Cascading Style Sheets, etc. In another embodiment, the computer code is malicious. The computer code is intercepted by the gateway **115**. The gateway **115** performs steps described below with reference to FIGS. **5** and **6**A-**6**D to analyze and collect data describing the computer code and/or determine whether the computer code is exhibiting behavior indicating that the computer code is malicious.

The network **130** is a conventional network and may have any number of configurations such as a star configuration, a token ring configuration or another configuration known to those skilled in the art. In various embodiments, the network **130** is a wireless network, a wired network or a combination of a wireless and a wired network. Furthermore, the network **130** may be a local area network (LAN), a wide area network (WAN) (e.g., the Internet) and/or any other interconnected data path across which multiple devices may communicate. In yet another embodiment, the network **130** may be a peer-to-peer network.

The network **130** may also be coupled to, or include, portions of a telecommunications network for communicating data using a variety of different communication protocols. In yet another embodiment, the network **130** includes a Bluetooth communication network and/or a cellular communications network for sending and receiving data (e.g., 3G and/or 4G network). For example, the network **130** transmits and/or receives data using one or more communication protocols such as short messaging service (SMS), multimedia messaging service (MMS), hypertext transfer protocol, direct data connection, WAP, email or another suitable communication protocol.

A server **120** or a data source **140** is a computing device including data processing and communication capabilities. For purposes of illustration, FIG. **1** illustrates a system **100** including a first server **120**A and a second server **120**B; however, in other embodiments, the system **100** includes any number of servers **120**. For example, a server **120** includes a processor, a communication unit and a storage device. However, in other embodiments, a server **120** may include different and/or additional components. A server **120** receives a data request from a client device **110** and transmits data to the client device **110** via the network **130**. In one embodiment, a server **120** generates data or modifies data responsive to the data request. Different processes executed by the client device **110** may generate data requests for different servers **120**. For example, a first process executed by the client device **110** generates a data request that is communicated to a first server **120**A, while a second process executed by the client device **110** generates a data request that is communicated to a second server **120**B.

In one embodiment, the system **100** includes a behavior server **150** coupled to the gateway **115** and/or the client device **110** via the network **130**. The behavior server **150** is a computing device having data processing and data communication capabilities that includes data describing malicious data requests or data requests associated with malware (e.g., malicious computer code). In one embodiment, the behavior server **150** stores attributes of malicious computer code in a database. The database is communicated from the behavior server **150** to the gateway **115**, which subsequently compares attributes of computer code intercepted by the gateway **115** from one or more of the non-trusted devices (e.g., server **120**A, **120**B and data source **140**) with the database to identify malicious computer code. In one embodiment, malicious compute code is computer code that makes data requests that will harm the client device **110** and/or the gateway **115**, or attempts unauthorized transmission of data stored on storage device associated with the client device **110** and/or gateway **115** to a non-trusted device. Additionally, the behavior server

150 communicates with the gateway **115** or the client device **110** via the network **130** to update the database, allowing the gateway **115** to use the most current data for identifying malicious computer code. For example, the behavior server **150** transmits an updated database to the gateway **115** or to the client device **110** when additional attributes of malicious computer code are identified.

For example, the behavior server **150** executes malware in one or more virtual machines and captures the data requests generated by the malware. The behavior server **150** then analyzes the data requests to identify one or more attributes of data requests produced by the executing malware. For example, the behavior server **150** identifies a User-Agent, a Computer Name, a Media Access Control Address, a Uniform Resource Indicator and/or a file name from the data requests generated by the malware and analyzes one or more of the attributes generated by different malware to determine characteristics of malicious data requests based on the different types of generated data requests. In one embodiment, the behavior server **150** generates one or more rules identifying attributes of malicious data requests based on analysis of the malicious data requests generated by multiple executing malware. Thus, the rules generated by the behavior server **150** specify attributes indicative of malicious data requests.

For example, the behavior server **150** analyzes the User Agent portion of data requests to identify User Agent portions commonly associated with malicious data requests. The User Agent portion of a data request is a text string that is sent from a client device **110** to a server **120** identifying the process or application generating the data request. In one embodiment, the behavior server **150** includes a blocking listing of User Agent data associated with malicious data requests, such as User Agent data used by different malware. This blocking listing is communicated to the gateway **115** and when the gateway **115** receives a data request including a User Agent portion matching an entry in the blocking listing, the data request is blocked. Alternatively, the behavior server **150** includes an authorized listing including User Agent data associated with legitimate processes. In one embodiment, the authorized listing is communicated to a gateway **115** to allow the gateway **115** to block a data request including a User Agent portion not included in the authorized listing. Alternatively, the behavior server **150** includes both a blocking listing and an authorized listing and communicates both the blocking listing and the authorized listing to a gateway **115**. Additional examples of rules generated by the behavior server **150** and used by the gateway **115** to identify malicious data requests are further described below in conjunction with FIGS. **5** and **6A-6D**.

Client Device **110**

FIG. **2** is a block diagram of a client device **110**. The client device **110** comprises a processor **220**, a memory **216**, a storage device **202** (sometimes referred to herein as "storage **202**") and a browser **210** stored on the storage device **202**.

The processor **220**, memory **216**, storage device **202** and browser **210** are communicatively coupled to one another via a bus **205**. The processor **220** is communicatively coupled to the bus **205** via signal line **255**. The memory **216** is communicatively coupled to the bus **205** via signal line **265**. The storage device **202** is communicatively coupled to the bus **205** via signal line **275**. The browser **210** communicates with the other elements of the client device **110** via the signal line **275**.

The processor **220** comprises an arithmetic logic unit, a microprocessor, a general purpose controller or some other processor array to perform computations and provide electronic display signals to a display device. The processor **220** is coupled to the bus **205** for communication with the other components. Processor **220** processes data signals and may comprise various computing architectures including a complex instruction set computer (CISC) architecture, a reduced instruction set computer (RISC) architecture, or an architecture implementing a combination of instruction sets. Although only a single processor is shown in FIG. **2**, multiple processors may be included. The processing capability may be limited to supporting the display of images and the capture and transmission of images. The processing capability might be enough to perform more complex tasks, including various types of feature extraction and sampling. It will be obvious to one skilled in the art that other processors, operating systems, sensors, displays and physical configurations are possible.

The memory **216** stores instructions and/or data that may be executed by processor **220**. The memory **216** is coupled to the bus **205** for communication with the other components. The instructions and/or data may comprise code for performing any and/or all of the techniques described herein. The memory **216** may be a dynamic random access memory (DRAM) device, a static random access memory (SRAM) device, flash memory or some other memory device known in the art. In one embodiment, the memory **216** also includes a non-volatile memory or similar permanent storage device and media such as a hard disk drive, a floppy disk drive, a CD-ROM device, a DVD-ROM device, a DVD-RAM device, a DVD-RW device, a flash memory device, or some other mass storage device known in the art for storing information on a more permanent basis.

The storage device **202** is a non-transitory computer-readable memory configured to store computer code. For example, the storage device **202** is a non-volatile storage medium such as a hard drive, flash memory, etc. The storage device **202** stores the browser **210**. The processor **220** accesses and executes the browser **210**.

The browser **210** is a web browser stored on the on the storage device **202** and configured for two-way communication with the gateway **115**. For example, the browser **210** is a software application such as Mozilla FireFox, Windows Internet Explorer, Google Chrome, Apple Safari, Opera, etc. In one embodiment, the browser **210** communicates with the network **130** via the gateway **115**.

Gateway **115**

FIG. **3** is a block diagram of one embodiment of a gateway **115**. In the embodiment shown by FIG. **3**, the gateway **115** includes a processor **310**, a storage device **320**, a communication device **330** and a detection module **340** communicatively coupled to each other via a bus **305**. However, in other embodiments, the gateway **115** includes different and/or additional components than the ones shown by FIG. **3**. The processor **310** is communicatively coupled to the bus **305** via signal line **355**. The storage device **320** is communicatively coupled to the bus **305** via signal line **365**. The communication device **330** is communicatively coupled to the bus **305** via signal line **375**.

The processor **310** is an arithmetic logic unit, a microprocessor, a general purpose controller or some other processor array to perform computations or other data processing that is coupled to the bus **305** for communication with the other components of the gateway **115**. The processor **310** provides similar functionality as the processor **220** described above with reference to FIG. **2**, so that description will not be repeated here.

The storage device **320** is a non-transitory computer-readable memory that stores instructions and/or data that may be executed by processor **310**. The stored instructions and/or data may be code for performing any and/or all of the functionality described herein when executed by the processor

310. For example, the storage device **320** includes instructions that, when executed by the processor **310**, cause the processor **310** to execute the steps further described below in conjunction with FIGS. **5** and **6**A-**6**D. In one embodiment, the storage device **320** is a non-volatile memory device or similar persistent storage device and media. For example, the storage device **320** may be a hard disk drive, a floppy disk drive, a CD-ROM device, a DVD-ROM device, a DVD-RAM device, a DVD-RW device, a flash memory device or another mass storage device known in the art. In one embodiment, the storage device **320** comprises a dynamic random access memory (DRAM) device, a static random access memory (SRAM) device, flash memory or some other memory device known in the art. In another embodiment, the storage device **320** comprises a combination of persistent memory and non-persistent memory. The storage device **320** is coupled to the bus **305** to communicate with other components of the gateway **115**.

In one embodiment, the storage device **320** stores a tree builder **322**, a static analyzer **324**, a behavior store **326** and tree data **328**. In another embodiment, the tree builder **322** is included in the static analyzer **324** so that the tree builder **322** is an element of the static analyzer **324**. For example, the tree builder **322** is a parser and the static analyzer **324** is a specially configured compiler that includes the tree builder **322** as a parser element of the compiler. In another embodiment, the tree builder **322** and the static analyzer **324** are each elements of a specially configured compiler that semi-analyzes and semi-executes computer code to determine information included in the tree data **328**.

The tree builder **322** is a parser that, when executed by the processor **310**, pareses the computer code received from the web application **122** and/or the data source **140** and builds a tree based at least in part on the computer code. In one embodiment, the tree builder **322** builds an AST tree. In other embodiments, the tree builder **322** builds another type of tree-based data structure. The tree builder **322** stores the tree on a non-transitory memory such as the storage device **320**. For example, the tree is stored in the tree data **328**.

In one embodiment, each node of the tree includes one or more statements from the original computer code. In another embodiment, a node of the tree corresponds to a construct occurring in the computer code.

In one embodiment, the tree built by the tree builder **322** is a binary representation of the computer code. A human user or processor-executed computer program (e.g., a compiler) can directly map the tree to the computer code. A human user or processor-executed computer program can also map the computer code back to the tree built by the tree builder **322**. For example, the tree can be mapped to the computer code based at least in part on the binary representation present in the tree. In one embodiment, the tree builder **322** does not build the tree using machine code. Instead, the tree builder **322** builds the tree using any normalized representation of the computer code that is executable by the processor **310** and/or understandable by the static analyzer **324**.

In one embodiment, the tree builder **322** embeds one or more probes in the tree. The probe is a function that is communicatively coupled to call the static analyzer **324** and provide information to the static analyzer **324**, the client device **110** or some other trusted device describing the progress of analyzing the computer code or a subset of the computer code. For example, the probe is communicatively coupled to the static analyzer **324** to provide the static analyzer **324** with information describing the progress of the static analyzer **324** in analyzing the computer code. The probe is described in greater detail with reference to FIGS. **6**A-**6**D.

In one embodiment, the tree builder **322** is a compiler that parses the computer code received from the web application **122** and/or the data source **140** and builds a tree based at least in part on the computer code.

In another embodiment, the tree builder **322** is a combination of a lexical analyzer and a parser that, when executed by the processor **310**, builds a tree representing the computer code.

The static analyzer **324** is code and routines that, when executed by the processor **310**, analyzes the tree built by the tree builder **322**. For example, the static analyzer **324** is a specially configured compiler that, when executed by the processor **310**, analyzes the tree to build and update the symbol table and the context table. The static analyzer **324** is configured to walk one or more nodes of the tree and analyze the one or more nodes. In one embodiment, each node of the tree has one or more statements parsed from the computer code by the tree builder **322** and the static analyzer **324** analyzes these statements. The static analyzer **324** builds and/or updates the symbol table and the context table. The symbol table and the context table are described above with reference to FIG. **1**, so that description will not be repeated here. The static analyzer **324** determines if the one or more statements are simple. If the statements are simple the static analyzer **324** executes them and further updates the symbol table and/or the context table (e.g., with updated value data and/or context data). The static analyzer **324** is described in more detail with reference to FIGS. **4**, **5** and **6**A-**6**D.

The tree data **328** is data including the symbol table and the context table. The tree data is described in more detail below with reference to FIG. **4**.

In one embodiment, the storage device **320** includes a behavior store **326** and a detection module **340**. The behavior store **326** includes one or more rules identifying attributes of malicious data requests. For example, the behavior store **326** includes a rule identifying data requests including a Media Access Control (MAC) as malicious, as most known processes do not include a MAC address in a data request. As another example, the behavior store **326** includes a listing of suspicious uniform resource indicators (URIs) for identifying malicious data requests based on a URI included in the data request. As yet another example, the behavior store **326** includes a listing of one or more file names associated with malware, so that data requests including a reference to a listed file name are identified as malicious.

In one embodiment, the behavior store **326** also includes rules identifying attributes or properties of malicious data received from a server **120** or data source **140** in response to a data request. For example, the behavior store **326** associates types of responses from a server **120** or data source **140** with malicious data requests to aid in identification of malicious data requests. In one embodiment, if the server **120** or data source **140** returns less data than an amount of data associated with benign data requests, the behavior store **326** indicates that the data request prompting data transmission is malicious. Similarly, the behavior store **326** associates a data request prompting receipt of a fake error message from a server **120** as a malicious data request. Classifying data requests based on attributes of the received data as well as attributes of the corresponding data request allows the gateway **115** to more accurately identify malicious data requests.

The detection module **340** extracts attributes from a received data request and/or from received data and compares the extracted attributes to the contents of the behavior store **326**. In one embodiment, the detection module **340** parses a data request into different attributes and compares at least a subset of the attributes to rules stored by the behavior store

326. In another embodiment, the detection module **340** extracts a subset of attributes of a data request and/or of received data and determines whether the subset of attributes are associated with malicious data requests based on the one or more rules stored in the behavior store **326**. In yet another embodiment, the detection module **340** also extracts a subset of the data received by the gateway **115** responsive to a data request and compares the extracted subset of the received data to the content of the behavior store **326** to further determine whether the data request is malicious. The functionality of the behavior store **326** and the detection module **340** is further described below in conjunction with FIGS. **5** and **6**A-**6**D.

The communication device **330** receives data requests from a client device **110** and transmits the data request to a server **120** or a data source **140** via the network **130**. The communication device **330** also receives data from the server **120** or from the data source **140** via the network **130** and communicates the data to the client device **110**. In one embodiment, the communication device **330** includes a port for direct physical connection to the network or to another communication channel. For example, the communication device **330** includes a USB, SD, CAT-5 or similar port for wired communication with the network. In another embodiment, the communication device **330** includes a wireless transceiver for exchanging data with the network, or with another communication channel, using one or more wireless communication methods, such as IEEE 802.11, IEEE 802.16, BLUETOOTH® or another suitable wireless communication method.

In yet another embodiment, the communication device **330** includes a cellular communications transceiver for sending and receiving data over a cellular communications network such as via short messaging service (SMS), multimedia messaging service (MMS), hypertext transfer protocol (HTTP), direct data connection, WAP, e-mail or another suitable type of electronic communication. In still another embodiment, the communication device **330** includes a wired port and a wireless transceiver. The communication device **330** also provides other conventional connections to the network for distribution of files and/or media objects using standard network protocols such as TCP/IP, HTTP, HTTPS and SMTP as will be understood to those skilled in the art.

Static Analyzer **324**

FIG. **4** is a block diagram of one embodiment of a static analyzer **324**. The static analyzer **324** comprises a tree walker **410** and a statement tester **430**. The tree walker **410** and the statement tester **430** are communicatively coupled to one another via a bus **405**. The bus **405** is also communicatively coupled to the tree data **328**. The tree walker **410** and the statement tester **430** store and access data in the tree data via the bus **405**. The tree walker **410** is communicatively coupled to the bus **405** via signal line **455**. The statement tester **430** is communicatively coupled to the bus **405** via signal line **475**. The tree data **328** is communicatively coupled to the bus **405** via signal line **465**.

The tree walker **410** is code and routines that, when executed by the processor **310**, walks and analyzes one or more nodes of the tree built by the tree builder **322**. For example, the tree walker **410** is code and routines configured to walk the tree built by the tree builder **322** using one or more of a tree grammar, a manual tree walker and an abstract syntax tree walker. In one embodiment, the tree walker **410** includes the functionality of a parser. In another embodiment, the tree walker **410** includes the functionality of a compiler that includes a parser.

In one embodiment, each node of the tree has a statement parsed from the computer code by the tree builder **322**. For each node walked, the tree walker **410** parses the statement to identity one or more of the variables in the statement. The tree walker **410** determines whether the identified variable is already stored in the symbol table **422**. The tree walker **410** stores the variable and the value for the variable in the symbol table **422** responsive to determining that the variable is not already stored in the symbol table **422**. The tree walker **410** updates the value for the variable in the symbol table **422** responsive to determining that the variable is already stored in the symbol table **422**.

Next the tree walker **410** determines whether the statement is a control structure. If the statement is a control structure, the tree walker **410** determines the scope of the control structure. Responsive to determining that the statement is a control structure, the tree walker **410** further updates the context table **424** with context data describing the scope of the control structure. If the statement is not a control structure, the tree walker **410** does not update the context table **424**. Instead, the tree walker **410** determines whether or not a probe function is included in the statement. The tree walker **410** calls the probe responsive to determining that a probe function is included in the statement.

The tree walker **410** determines whether the statement is completed. A statement is completed if the scope of the statement has been met (e.g., if the life of statement scope is expired). If the statement is completed, the tree walker **410** resets the statement scope. If the statement is not completed (i.e., the scope of the statement has not been met), the tree walker **410** updates the context table **424** with scope data describing the current scope of the statement and the statement's sub-statements (if any).

The tree walker **410** determines if a probe function is installed at the node. If a probe is installed, the tree walker **410** calls the probe.

The tree walker **410** analyzes the statement to determine if it is a simple statement. In one embodiment, a simple statement is a statement that only includes one or more basic language operators (e.g., plus, minus, etc.) applied to one or more variables. In one embodiment, a simple statement is a statement that only includes one or more function codes provided by the language in which the computer code is written. For example, the computer code is written in JavaScript and the statement includes one or more JavaScript functions. In one embodiment, if a statement includes any custom functions provided by a human user, then the statement is not simple. For example, if a statement includes one or more user-defined functions, then the statement is not simple since a simple statement is a statement that does not include any user-defined functions. If the statement is a simple statement, the tree walker **410** communicates with the statement tester **430** to indicate that the statement should the tested. After testing the statement is completed, the tree walker **410** updates the symbol table **422** and the context table **424** to include information describing the observed variables and the associated scope of these variables. For example, the tree walker **410** updates the symbol table **422** and the context table **424** as described below for FIGS. **6**C and **6**D.

The statement tester **430** is code and routines that, when executed by the processor **310**, executes the statement. The statement tester **430** communicates with the tree walker **410** to signal to the tree walker **410** to update the symbol table **422** and the context table **424** responsive to executing the statement. In one embodiment, the statement tester **430** communicates to the detection module **340** to monitor for suspicious behavior by the statement responsive to executing the statement.

In one embodiment, upon execution by the processor **310**, tree builder **322**, tree walker **410**, statement tester **430** and the detection module **340** provide the functionality described below with reference to FIGS. **5** and **6**A-6D.

The symbol table **422** and the context table **424** are stored on the storage device **320**. The symbol table **422** and the context table **424** are described above, so that description will not be repeated here.

Methods

FIG. **5** is a flow chart of a method **500** for using a static analyzer **324** to analyze computer code. The client device **110** makes a request to the web application **122**. The web application **122** transmits computer code to the client device **110**. For example, the web application **122** transmits a dynamic script (e.g., JavaScript, Hypertext Transfer Protocol, etc) to the client device **110**. The gateway **115** intercepts the computer code. The tree builder **322** builds a tree **510** representing the computer code. The tree builder **322** communicates with the static analyzer **324** to begin walking the tree. In one embodiment, each node of the tree includes one or more statements parsed by the tree builder **322** from the computer code. The static analyzer **324** determines **520** whether all the nodes of the tree are walked. If all the nodes of the tree are walked, the static analyzer **324** ends the method **500**. If all of the nodes of the tree are not walked, the method **500** moves to step **530** and the static analyzer **324** walks to the next un-walked node. The static analyzer **324** analyzes **540** the node and updates the symbol table **422** and/or the context table **424**. The static analyzer **324** executes a statement and communicates with the detection module **340** to determine whether the executed statement exhibits suspicious behavior. The detection module **340** determines **550** whether the executed statement exhibited suspicious behavior. If the detection module **340** determines **550** that the executed statement did not exhibit suspicious behavior, the method **500** returns to step **520**. If the detection module **340** determines **550** that the executed statement did exhibit suspicious behavior, the method **500** moves to step **560** and the gateway **115** blocks the computer code.

FIG. **6** is a flow chart of a method **600** for using a static analyzer **324** to analyze computer code. The client device **110** makes a request to the web application **122**. The web application **122** transmits computer code to the client device **110**. For example, the web application **122** transmits a dynamic script (e.g., JavaScript, Hypertext Transfer Protocol, etc) to the client device **110**. The gateway **115** intercepts the computer code. The tree builder **322** builds a tree representing the computer code. The tree builder **322** communicates with the static analyzer **324** to begin walking the tree. The tree walker **410** initiates **610** walking a tree built by the tree builder **322**. For each node walked, the tree walker **410** parses the statement to identify **612** one or more of the variables in the statement. The tree walker **410** determines **614** whether the identified variable is already stored in the symbol table **422**. The tree walker **410** stores **616** the variable name and the value for the variable in the symbol table **422** responsive to determining that the variable is not already stored in the symbol table **422**. The tree walker **410** updates **618** the value for the variable in the symbol table **422** responsive to determining that the variable is already stored in the symbol table **422**.

At step **620**, the tree walker **410** determines whether the statement is a control structure. If the statement is not a control structure, the method **600** proceeds to step **622** and the tree walker **410** does not update the context table **424**. Instead, the method **600** advances to step **660** (step **660** is described below). If the statement is a control structure, the method **600** proceeds to step **624** and the tree walker **410** determines the scope of the control structure and updates the context table **424** with context data describing the scope of the control structure.

At step **630**, the tree walker **410** determines whether the statement is completed. A statement is completed if the scope of the statement has been met (e.g., if the life of statement scope is expired). If the statement is completed, the method **600** proceeds to step **650** and the tree walker **410** resets the statement scope to the original value based at least in part on the scope of the variable to which the statement belongs as indicated by the context table **424**. The method **600** advances to step **660** (step **660** is described below).

If the statement is not completed (i.e., the scope of the statement has not been met), the method **600** proceeds to step **640** and the tree walker **410** does not reset the current statement scope. Instead, the method **600** proceeds to step **652** and the tree walker **410** updates the context table **424** with scope data describing the current scope of the statement and the statement's sub-statements (if any).

The method proceeds to step **660**. At step **660**, the tree walker **410** determines if a probe function ("a probe") is installed at the node. If a probe is not installed, the method **600** proceeds to step **662** and the tree walker **410** does not call a probe. If a probe is installed, the method **600** advances to step **664** and the tree walker **410** calls the probe.

At step **670**, the tree walker **410** analyzes the statement to determine if it is a simple statement. If the tree walker **410** determines that statement is not a simple statement, the method moves to step **696**. At step **696**, the tree walker **410** determines whether all the nodes of the tree are walked. If all the nodes of the tree are walked, the method ends. If all of the nodes of the tree are not walked, the method **600** moves to step **698** and the tree walker **410** walks to the next un-walked node. The method then returns to step **612**. If the statement is a simple statement, the method **600** moves to step **674** and the tree walker **410** communicates with the statement tester **430** to indicate that the statement should be tested by the statement tester **430**. The statement tester **430** communicates with the tree walker **410** to indicate that the statement is about to be executed.

The statement tester **430** executes **674** the statement. In one embodiment, executing the statement reveals the actual variable names, values and scopes. The tree walker **410** identifies **676** one or more variable names. At step **678**, the tree walker **410** determines whether the identified variable is already stored in the symbol table **422**. The tree walker **410** stores **680** the variable name and the value for the variable in the symbol table **422** responsive to determining that the variable is not already stored in the symbol table **422**. The tree walker **410** updates **682** the value for the variable in the symbol table **422** responsive to determining that the variable is already stored in the symbol table **422**.

At step **684**, the tree walker **410** determines whether the statement is a control structure. If the statement is not a control structure, the method **600** proceeds to step **685** and the tree walker **410** does not update the context table **424**. If the statement is a control structure, the method **600** proceeds to step **686** and the tree walker **410** determines the scope of the control structure and updates the context table **424** with context data describing the scope of the control structure.

Contemporaneous to execution of the statement (e.g., step **674**), the static analyzer **324** communicates with the detection module **340** to indicate to the detection module **340** that the statement will be executed. At step **688**, the detection module **340** analyzes the behavior of the executed statement using the data stored in the behavior store **326**. The detection module

340 determines **690** whether the executed statement exhibited suspicious behavior. If no suspicious behavior is detected by the detection module **340**, the method returns to step **696**. If suspicious behavior is detected by the behavior module **340**, the method **600** goes to step **694**. At step **694**, the method **600** either returns to step **696** or blocks the computer code (e.g., based on input received from a human administrator of the gateway **115**).

The foregoing description of the embodiments of the present invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the present invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the present invention be limited not by this detailed description, but rather by the claims of this application. As will be understood by those familiar with the art, the present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Likewise, the particular naming and division of the modules, routines, features, attributes, methodologies and other aspects are not mandatory or significant, and the mechanisms that implement the present invention or its features may have different names, divisions and/or formats. Furthermore, as will be apparent to one of ordinary skill in the relevant art, the modules, routines, features, attributes, methodologies and other aspects of the present invention can be implemented as software, hardware, firmware or any combination of the three. Also, wherever a component, an example of which is a module, of the present invention is implemented as software, the component can be implemented as a standalone program, as part of a larger program, as a plurality of separate programs, as a statically or dynamically linked library, as a kernel loadable module, as a device driver, and/or in every and any other way known now or in the future to those of ordinary skill in the art of computer programming. Additionally, the present invention is in no way limited to implementation in any specific programming language, or for any specific operating system or environment. Accordingly, the disclosure of the present invention is intended to be illustrative, but not limiting, of the scope of the present invention, which is set forth in the following claims.

What is claimed is:

1. A computer-implemented method comprising:

parsing, via a processor, computer code received from a non-trusted entity via a network, the computer code received by a gateway when sent by the non-trusted entity to a client device in response to a request from the client device;

transforming, via the processor, the parsed computer code into an abstract syntax tree, the abstract syntax tree containing a first node having a statement from the parsed computer code;

analyzing, via the processor, the statement in the first node to determine if the statement contains a user-defined function;

in response to determining that the statement in the first node does not contain the user-defined function, executing the statement; and

determining the computer code is malicious by comparing a result of the execution of the statement in the first node to a set of rules denoting malicious behavior.

2. The computer-implemented method according to claim **1**, wherein analyzing the statement in the first node to determine if the statement contains theuser-defined function further comprises:

identifying a variable contained in the first node;

identifying symbol data describing the variable, the symbol data including a name of the variable and a value associated with the variable; and

storing the symbol data in a symbol table.

3. The computer-implemented method according to claim **2**, further comprising:

determining context data associated with the statement, the context data describing a scope of the statement;

caching the context data in a context table; and

associating the context data in the context table with corresponding symbol data in the symbol table.

4. The computer-implemented method according to claim **1**, further comprising:

determining if the first node includes a probe function; and

in response to determining that the first node does not include the probe function, inserting the probe function in the first node.

5. The computer-implemented method according to claim **1**, further comprising:

determining if the statement in the first node is a simple statement, the simple statement being a statement having a basic language operator applied to a variable and a function code associated with a standard library of a programming language of the computer code.

6. The computer-implemented method according to claim **2**, wherein executing the statement further comprises:

detecting induced changes to the symbol data after executing the statement; and

updating the symbol table to reflect the induced changes to the symbol data.

7. The computer-implemented method according to claim **1**, further comprising, in response to determining that the computer code is malicious, blocking the computer code.

8. A tangible computer readable storage device or storage disc comprising instructions that, when executed, cause a gateway device to at least:

parse computer code received from a non-trusted entity via a network, the computer code received by the gateway when sent by the non-trusted entity to a client device in response to a request from the client device;

generate an abstract syntax tree from the parsed computer code, the abstract syntax tree containing a first node having a statement from the parsed computer code;

determine if the statement in the first node contains a user-defined function;

in response to determining that the statement in the first node does not contain the user-defined function, executing the statement; and

determine the computer code is malicious by comparing a result of the execution of the statement in the first node to a set of rules denoting malicious behavior.

9. The tangible computer readable storage device or storage disc of claim **8**, wherein the instructions further cause the gateway device to:

identify a variable contained in the first node;

identify symbol data describing the variable, the symbol data including a name of the variable and a value associated with the variable; and

store the symbol data in a symbol table.

10. The tangible computer readable storage device or storage disc of claim **8**, wherein the instructions further cause the gateway device to:

determine context data associated with the statement, the context data describing a scope of the statement;

cache the context data in a context table; and

associate the context data in the context table with corresponding symbol data in the symbol table.

11. The tangible computer readable storage device or storage disc of claim **8**, wherein the instructions further cause the gateway device to:

determine if the first node includes a probe function; and

in response to determining that the first node does not include the probe function, inserting the probe function in the first node.

12. The tangible computer readable storage device or storage disc of claim **8**, wherein the instructions further cause the gateway device to determine if the statement in the first node is a simple statement, the simple statement being a statement having a basic language operator applied to a variable and a function code associated with a standard library of a programming language of the computer code.

13. The tangible computer readable storage device or storage disc of claim **9**, wherein the instructions further cause the gateway device to:

detect induced changes to the symbol data after executing the statement; and

update the symbol table to reflect the induced changes to the symbol data.

14. The tangible computer readable storage device or storage disc of claim **8**, wherein the instructions further cause the gateway device to, in response to the determination that the computer code is malicious, block the computer code.

15. A device comprising:

a memory; and

a processor configured to:

parse computer code received from a non-trusted entity via a network, the computer code received by a gateway when sent by the non-trusted entity to a client device in response to a request from the client device;

transform the parsed computer code into an abstract syntax tree, the abstract syntax tree containing a first node having a statement from the parsed computer code;

analyze the statement in the first node to determine if the statement contains a user-defined function;

in response to determining that the statement in the first node does not contain the user-defined function, executing the statement; and

determine the computer code is malicious by comparing a result of the execution of the statement in the first node to a set of rules denoting malicious behavior.

16. The device of claim **15**, wherein the processor is further configured to:

identify a variable contained in the first node;

identify symbol data describing the variable, the symbol data including a name of the variable and a value associated with the variable; and

store the symbol data in a symbol table.

17. The device of claim **16**, wherein the processor is further configured to:

determine context data associated with the statement, the context data describing a scope of the statement;

cache the context data in a context table; and

associate the context data in the context table with corresponding symbol data in the symbol table.

18. The device of claim **16**, wherein the processor is further configured to:

determine if the statement in the first node is a simple statement, the simple statement being a statement having a basic language operator applied to a variable and a function code associated with a standard library of a programming language of the computer code.

19. The device of claim **16**, wherein the processor is further configured to:

detect induced changes to the symbol data after executing the statement; and

update the symbol table to reflect the induced changes to the symbol data.

20. The device of claim **16**, wherein the processor is further configured to, in response to the determination that the computer code is malicious, block the computer code.

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